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CYGNUS SYSTEM TIMING*

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Abstract

The Cygnus Dual Beam Radiographic Facility consists of two identical radiographic sources each with a dose rating of 4-rad at 1 m, and a 1-mm diameter spot size. The development of the rod pinch diode was responsible for the ability to meet these criteria[1]. The rod pinch diode in a Cygnus machine uses a 0.75-mm diameter, tapered tip, tungsten anode rod extended through a 9-mm diameter, aluminum cathode aperture. When properly configured, the electron beam born off the aperture edge can self-insulate and pinch onto the tip of the rod creating an intense, small x-ray source. The Cygnus sources are utilized as the primary diagnostic on Subcritical Experiments that are single-shot, high-value events. The system timing on Cygnus will be evaluated as related to the following system elements: HV trigger generator, Marx, pulse forming line and rod pinch diode. Spare trigger generators will also be included in this evaluation.

I. GENERAL SYSTEM DESCRIPTION

The Cygnus machines are installed in an underground laboratory and as such require the small footprint shown in Figure 1. Other requirements were two machines that could be fired independently with x-ray beams intersecting at 60 degrees. The major components of Cygnus include: Marx Generator, Pulse Forming Line (PFL), Water Transmission Line (WTL), Inductive Voltage Adder (IVA), Vacuum Insulated Transmission Line (VITL), and Rod Pinch Diode.

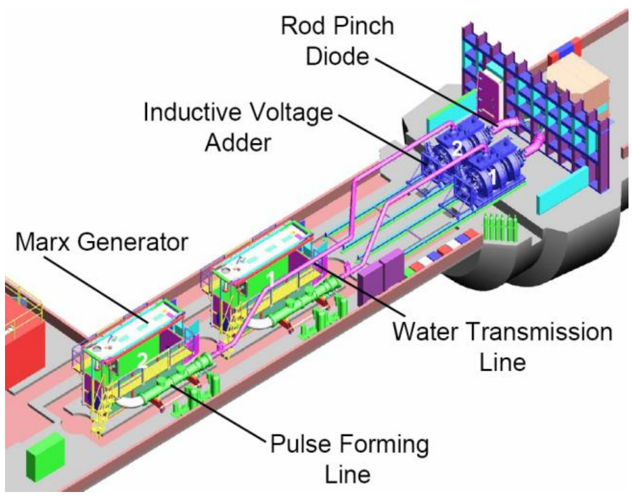

Figure 1. Cygnus layout.

II. CYGNUS TIMING DESCRIPTION

Consistency of dose measurements is the most important metric of Source performance [2]. Timing is also critical as Cygnus is one of multiple diagnostics used for Subcritical Experiments. In the normal operating

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mode, optical triggers are provided to the NRT-103 from the Central Fire Control Unit (CFCU) [3]. These redundant optical triggers are converted to electrical signals and trigger the Cygnus 1 and Cygnus 2 Stanford DG-535 (Digital Delay Generators).

The high voltage output of the DG-535 then triggers the Maxwell 40230 High Voltage Trigger Generators as shown in Figure 2. (Maxwell is now Pulsed Sciences Division of L-3 Communications).

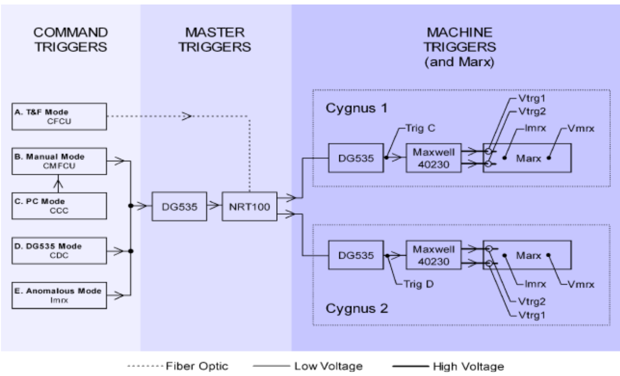

Figure 2. Cygnus Timing Block Diagram.

Bergoz Fast Current Transformers (Fig 3) are used to monitor the H.V. Trigger from the Maxwell 40230 High Voltage Trigger Generators.

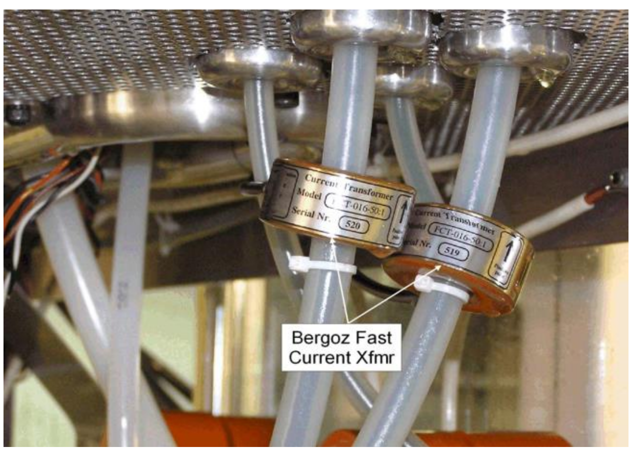

Figure 3. Bergoz Fast Current Transformers.

III. JITTER MEASUREMENTS

A. Measurements

Jitter was measured at four locations. VTRG2 is the output of the Maxwell Trigger Generators (Fig. 3). VPFL2 is immediately before the Main Switch which is also the output of the Marx. VPFL4 is after the Main Switch which feeds the WTL (Fig. 4). The last diagnostic location measured for the paper is IPLT, which consist of three current diagnostics on the end plate of the diode. This is the last electrical diagnostic of the machine and demonstrates the combined effect of jitter from the Trigger Generator, Marx circuit and PFL. A small amount of jitter in the diode may be caused by the self-break water switch (PFL SW) in the PFL.

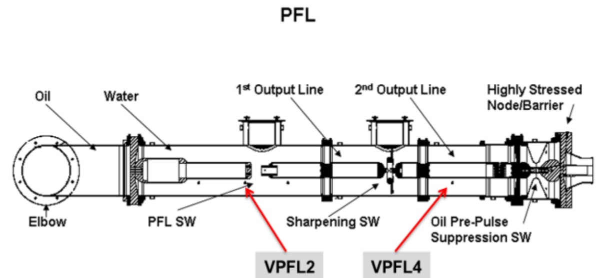

Figure 4. Cygnus Pulse Forming Line.

B. Three Series Comparison

Jitter was compared from three series of shots. The Armando series in 2004, the Pollux series in 2012 and the Ediza series earlier in 2019. These three series were selected as they represent the early shots on Cygnus, the middle (Pollux shots ended at Shot 1970) and Ediza series which concluded at Shot 4017.

The measurements are taken from zero time to 50% of full height as shown in Figure 5.

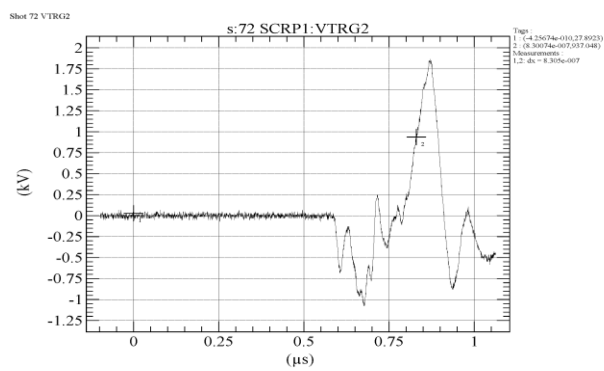

Figure 5. VTRG2 Sample Data Measurement.

C. Jitter Measurements from VTRG2

The measurements from VTRG2 indicate jitter from the Maxwell 40230 Trigger Generator. The Ediza series is plotted as it was a larger data set (99 shots) compared to using a 30-shot sample for Armando and Pollux data. The bins in the plot shown on Figure 6 and all subsequent plots are 8ns wide.

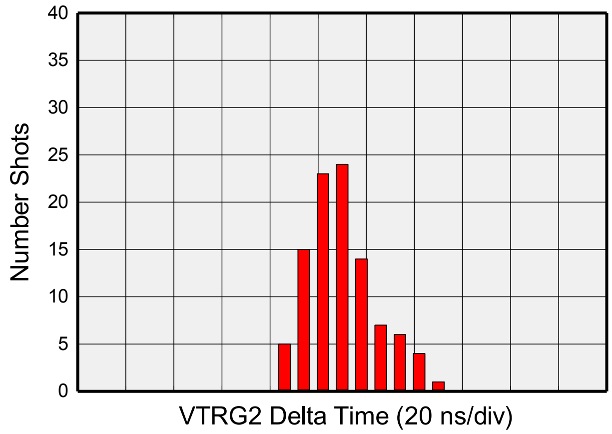

Figure 6. Cygnus 1 VTRG2 – Ediza Series

D. Jitter Measurements from VPFL2

The measurements from VPFL2 indicate jitter from the Marx circuit (Zero Air pressurized spark gaps). The Ediza series is once again plotted as it was a larger data set (99 shots) compared to using a 30-shot sample for Armando and Pollux data. Replacement or refurbishment of spark gaps would be expected to improve jitter.

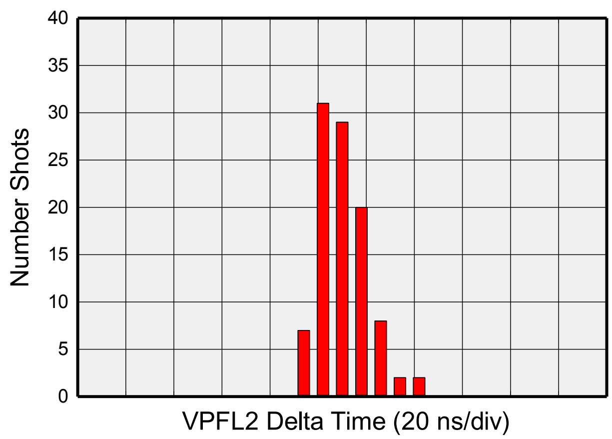

Figure 7. Cygnus 1 VPFL2 – Ediza Series

E. Jitter Measurements from VPFL4

The measurements from VPFL4 (Fig. 7) indicate jitter from the Main Switch (Self-Break Water Switch). Replacement or refurbishment of switch electrodes would be expected to improve jitter after a short series of conditioning shots.

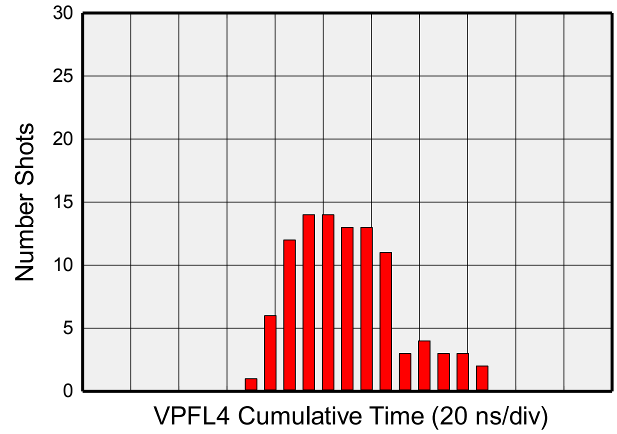

Figure 8. Cygnus 1 VPFL4 – Ediza Series

F. Jitter Measurements from IPLT

The measurements from IPLT (Fig. 9) indicate cumulative jitter from the Trigger Generator, Marx circuit and the self-break water switch in the PFL. There are no expected jitter sources after the PFL and the digitizer sample rate of 0.4ns accounts for the small difference in jitter after VPFL4.

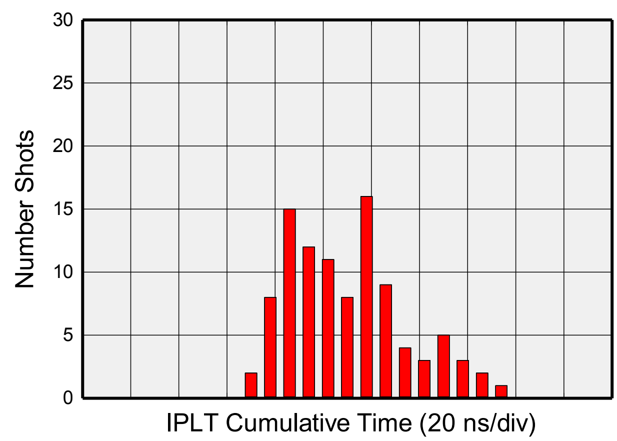

Figure 9. Cygnus 1 IPLT – Ediza Series

G. Cumulative and Component Jitter Comparison

The three experimental series shown in Table 1 display the additive nature of jitter in the system. Not shown are the dates trigger generators, Marx spark gaps or PFL electrodes were refurbished. Any of these activities would reduce jitter in the respective location.

Series Name	VTRG2 (Jitter in ns)	VPFL2 (Jitter in ns)	VPFL4 (Jitter in ns)	IPLT
Jitter due to:	Trigger Generator	Marx + TG	Marx + TG + PFL	Marx + TG + PFL + Diode
ARMANDO - 2004 (30 Shot Data Set)	10.6ns	15.9ns	20.6ns	19.9ns
POLLUX - 2012 (30 Shot Data Set)	3.5ns	4.4ns	10.4ns	10.4ns
EDIZA - 2019 (99 Shot Data Set)	14.1ns	19.1ns	21.8ns	23.9ns

Table 1. Cygnus Cumulative Jitter.

Using Propagation of Uncertainty, the component jitter was calculated as shown in Table 2.

Jitter due to:	Trigger Generator	Marx	PFL	Diode
Delta (Statistics*)	14.1	10.2	11.1	3.2

Table 2. Cygnus Component Jitter.

When these Delta values are plotted (Figures 10-13) the jitter from each individual source is plotted versus cumulative jitter as was previously shown in Figures 6-9.

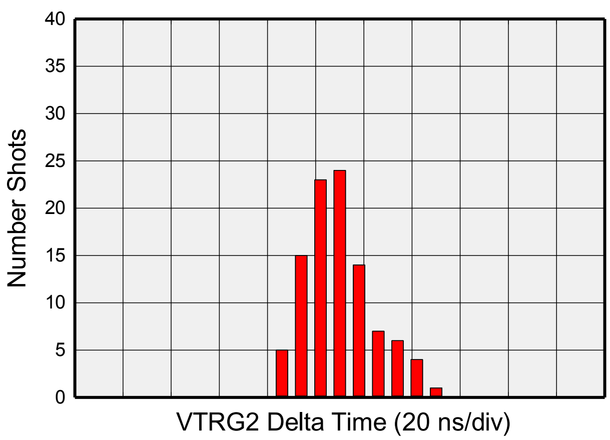

Figure 10. Cygnus 1 VTRG – Ediza Series

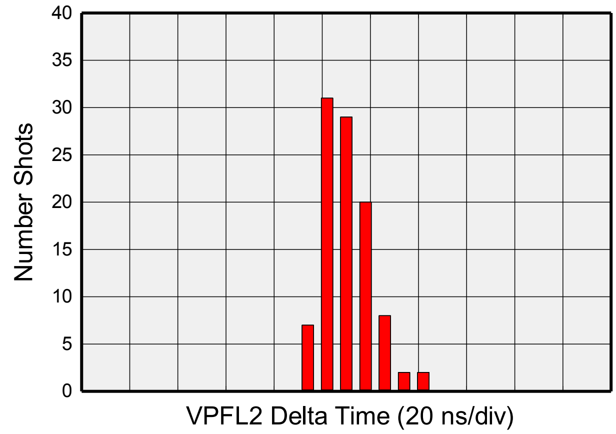

Figure 11. Cygnus 1 VPFL2 – Ediza Series

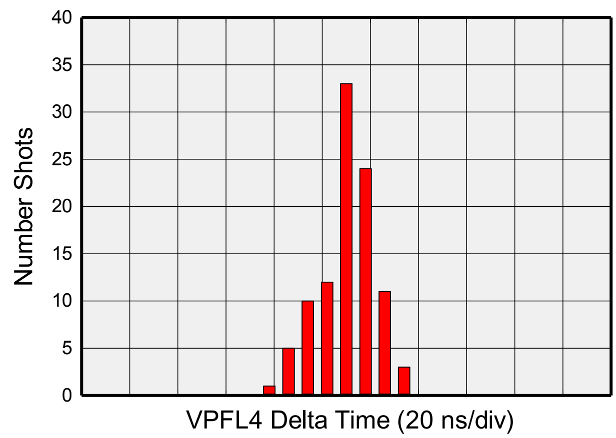

Figure 12. Cygnus 1 VPFL4 – Ediza Series

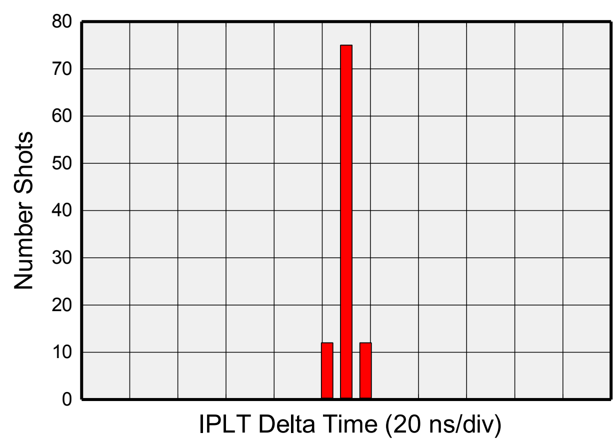

Figure 13. Cygnus 1 IPLT – Ediza Series

IV. TRIGGER GENERATOR TESTING

Two spare generators were installed. One unit had erratic operation in computer-controlled mode and will be repaired before jitter measurements are performed. The second unit shows higher deviation (Table 3) and will have spark gaps refurbished prior to re-testing.

HV Trigger Generator	Jitter in ns
Cygnus-1 Installed (A)	14.1ns
Cygnus-1 Spare (C)	22.3ns

Table 3. Cygnus Spare TG.

V. SUMMARY

Shot-to-shot reproducibility of x-ray parameters is an important demonstration that source quality is consistent, and that good radiography performance will likely be delivered[2]. The reproducibility of the Cygnus timing measurements has verified the system performance of the High Voltage Trigger Generator, Marx, and Pulse Forming Line maintenance has been sufficient for reliable performance. The data analysis indicates Cygnus jitter is relatively similar for the Trigger Generator, Marx and Pulse Forming Line in the Ediza Series.

Maintenance logs will be reviewed to determine if the lower jitter during the Pollux Series was shortly after one of the two major refurbishments (Refurbished Marx Spark Gaps and/or different Trigger Generator).

The spare Trigger Generators were evaluated, and one unit had erratic computer-controlled operation. The second unit has higher deviation/jitter and the spark gaps will be refurbished. Cygnus 2 data will be evaluated and compared to the Cygnus 1 data presented for the same series of shots.

VI. REFERENCES

[1] G. Cooperstein et al., "Theoretical Modeling and experimental Characterization of a Rod-Pinch Diode," in Physics of Plasmas, Vol. 8, Number 10, October 2001.

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[3] D. Nelson et al., “Cygnus Trigger System” in IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 36, NO. 5, OCTOBER 2008, pp. 334-337.